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# Welding Nickel Base Alloys

Welding parameters are established for the gas tungsten-arc and resistance spot welding of thin gage René 41 and Hastelloy X.

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## Introduction

Planning for re-entry and for super-sonic cruise vehicles indicates that extensive use of high temperature resistant materials will be required in the foil and medium gages. The nickel-base alloys, due to their strength at high temperatures and oxidation resistance properties, are candidate materials for these applications. They are readily available in the desired gages. However, the fabrication of these materials for missile and space vehicle applications will require extensive fusion and resistance welding for fastening. Thus the object of this project was to develop welding parameters for joining nickel-base alloys in the thin gages by the gas tungsten-arc and resistance spot welding methods. René 41 and Hastelloy X alloys were selected because of their potential use and their current availability.

## Background

The chemical compositions of the selected alloys appear in Table 1. These alloys are resistant to oxidizing, reducing and neutral atmospheres.

The optimum application condition for Hastelloy X alloy exists in the solution heat treated condition. Solution heat treatment is obtained by heating to 2150° F, followed by either a rapid air cool or water quench. Aging is not recommended. The normal room temperature tensile strength is 110,000 psi. It is usually selected for oxidation resistance and strength capabilities at elevated temperatures, and for its good forming and welding characteristics.

The René 41 alloy possesses good strength in the 1200 and 1800° F temperature range. The maximum

room temperature strength in the solution heat treated condition is approximately 170,000 psi. Solution heat treatment is obtained by heating to 1950° F, holding 4 hr followed by rapid air cooling. Aging at 1400° F for 16 hr may produce room temperature strength in excess of 200,000 psi. Assurance of consistent properties results from close control of interstitial and chemical elements by the arc vacuum remelting process.

Both alloys are ductile and can be formed readily. However, they do require higher forming pressures than the stainless steels, and stress relief heat treatment may be required after each cold work forming step.

Published information has shown that these alloys are weldable by either the gas tungsten-arc or resistance welding processes.

## Equipment

The welding equipment used for this project was of a type normally found in aircraft and missile production facilities. Equipment used for shearing, flanging and butt welding of foil gages must be precision and limited to the foil gages exclusively.

The resistance spot welding of foil and medium gage material was done with a special scissors-type portable gun. The transformer was 150 kva, controlled by a 3 phase, 10 cycle, frequency converter digital

timing control. Optimum welding heat settings were possible because of separate full range phase shift and timing controls for preheat, weld, post heat and temper functions.

The foil butt welding was done on a precision foil butt welding unit with a semiautomatic gas tungsten-arc welding electrode holder and a 1/4 to 10 amp filtered d-c power supply. Arc initiation at these low currents was accomplished with a tuned oscillator high frequency unit. The maximum variation of travel carried in the horizontal and vertical plane was less than 1/4 mil.

The butt welding of the medium gage material was done on a standard stake welding unit with a semi-automatic tungsten-arc welding electrode holder and a 300 amp a-c, d-c power supply. The stake unit was a standard production-type facility.

## Test Procedure

Welding parameters were developed for resistance spot and gas tungsten-arc fusion welding of each alloy in 0.005, 0.010 and 0.040 in. thicknesses. The welding schedules developed are suitable for production applications of flat and cylindrical sections. Three-piece tee sections were tungsten-arc welded to simulate attachment problems.

Extreme care was exercised in the edge preparation of the foil material to attain or preserve the conditions necessary for butt welding. Alignment of the butt edges to obtain contact throughout the length of the weld was essential.

Mechanical test data were compiled for the properties of welds made on material in the solution treated condition, solution treated and aged condition and solution treated welded and then aged condition. Tensile properties were correlated according to the direction of rolling. All test data was compared to base material control coupons for which physical data are listed in Table 2.

Representative photomicrographs

Table 1—Chemical Composition of René 41 and Hastelloy X, %

| Element    | René 41      | Hastelloy X  |
|------------|--------------|--------------|
| Chromium   | 18.0-20.0    | 20.5-23.0    |
| Iron       | 5.0 max.     | 17.0-20.0    |
| Cobalt     | 10.0-12.0    | 0.5-2.5      |
| Titanium   | 3.0-3.3      | ...          |
| Molybdenum | 9.0-10.5     | 8.0-10.0     |
| Aluminum   | 1.5          | ...          |
| Tungsten   | ...          | 0.2-1.0      |
| Carbon     | 0.12 max.    | 0.05-0.15    |
| Silicon    | 0.50 max.    | 1.0 max.     |
| Manganese  | ...          | 1.0 max.     |
| Nickel     | Bal.         | Bal.         |
|            | (approx. 50) | (approx. 47) |

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Table 2—Mechanical Property Data of Base Metal Control Coupons

| Thickness,<br>in.  | Direction of<br>shearing<br>to rolling | René 41                   |                              |                          | Hastelloy X               |                              |                          |
|--|--|---------------------------|------------------------------|--------------------------|---------------------------|------------------------------|--------------------------|
|  |  | Yield<br>strength,<br>psi | Ultimate<br>strength,<br>psi | Elong.<br>in 2 in.,<br>% | Yield<br>strength,<br>psi | Ultimate<br>strength,<br>psi | Elong.<br>in 2 in.,<br>% |
| Solution Heat Treated  |  |                           |                              |                          |                           |                              |                          |
| 0.005  | Transverse                             | 75,100                    | 133,100                      | 31.8                     | 62,266                    | 119,466                      | 26.8                     |
| 0.005  | Parallel                               | 74,866                    | 138,066                      | 33.8                     | 63,033                    | 120,930                      | 27.7                     |
| 0.010  | Transverse                             | 61,366                    | 134,866                      | 41.2                     | 53,770                    | 112,830                      | 37.2                     |
| 0.010  | Parallel                               | 62,733                    | 134,866                      | 47.8                     | 53,400                    | 113,400                      | 39.5                     |
| 0.040  | Transverse                             | 75,600                    | 140,590                      | 37.3                     | 56,800                    | 113,710                      | 39.2                     |
| 0.040  | Parallel                               | 79,433                    | 141,456                      | 43.3                     | 61,100                    | 113,130                      | 41.7                     |
| All coupons bent over IT thickness showed no apparent cracks |  |                           |                              |                          |                           |                              |                          |
| Solution Heat Treated & Aged <sup>a</sup>                    |  |                           |                              |                          |                           |                              |                          |
| 0.005  | Transverse                             | 132,900                   | 172,900                      | 9.0                      | 60,000                    | 94,000                       | 5.0                      |
| 0.010  | Transverse                             | 121,600                   | 161,200                      | 7.5                      | 53,100                    | 100,000                      | 12.5                     |
| 0.040  | Transverse                             | 143,400                   | 185,300                      | 11.0                     | 64,470                    | 118,420                      | 29.0                     |

<sup>a</sup> René 41 aging cycle: 1400° F. for 16 hr—air cool; Hastelloy X aging cycle: 1500° F. for 10 hr—air cool.

were taken of each test series. All René 41 metallographic specimens were etched with Marbles reagent. The Hastelloy X specimens were etched with hot aqua regia. All photomicrographs of weld structures were made at 40 or 50 diameters magnification.

### Foil Gage Tungsten-Arc Welding

Initial welding trials on the 0.005 and 0.010 in. thick material used square butt joints. It was impossible to weld the 0.005 in. material because of overlap during welding which caused burn-through, arc wander and lack of penetration.

The 0.010 in. material could be welded in 8 in. lengths by tacking prior to welding. Longer lengths would overlap prior to completing the weld.

Due to lack of slitting and flanging facilities, the material was finished sheared with a 0.016 in. standing flange. This was accomplished by placing a 0.016 in. spacer strip on the shear platen; the foil material was then clamped to the platen under a stiffened straight edge and a final 1/4 in. shear cut was made. This method produced an edge with a uniform standing flange and a sharp radius. It was ade-

quate for welding 0.005, 0.010 up to 0.016 in. material but not desired precision for thinner material.

With the 0.016 in. flange preparation, welds were made in 8 and 16 in. lengths. Table 3 contains the mechanical properties and weld schedules. The face of the welds had medium reinforcements and the root of the welds had light drop through. The René 41 and Hastelloy X cross sections are visible in Figs. 1 and 2 respectively. The face and root surfaces were clean and bright.

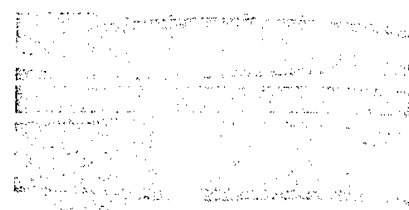


Fig. 1—Top: 0.005 in. René 41 flange butt weld (test 2). Bottom: 0.010 in. René 41 square butt weld (test 4)

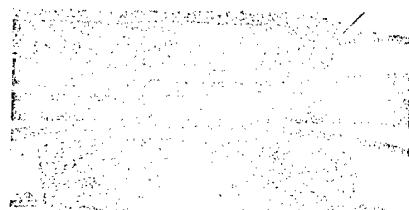


Fig. 2—0.005 and 0.010 in. Hastelloy X flanged butt welds (tests 5 and 7)

Table 3—Mechanical Properties and Weld Schedules of Solution Heat Treated and Butt Welded Foil Gage Material

| Test | Material    | Gage, <sup>a</sup><br>in. | Testing to<br>rolling<br>direction <sup>b</sup> | Yield<br>strength,<br>psi | Ultimate<br>strength,<br>psi | Elong<br>in 2<br>in., % | Location of<br>fracture <sup>c</sup> | Weld<br>efficiency, <sup>d</sup><br>% | Loss of<br>elonga-<br>tion, <sup>e</sup> % | 180 deg bend<br>over IT <sup>f</sup> |
|------|-------------|---------------------------|---|---------------------------|------------------------------|-------------------------|--------------------------------------|---------------------------------------|--|--------------------------------------|
| 1    | René 41     | 0.005                     | Parallel  | 78,300                    | 129,300                      | 20.3                    | HA                                   | 93.5                                  | 40.0                                       | No cracks                            |
| 2    | René 41     | 0.005                     | Transverse                                      | 74,300                    | 114,809                      | 16.3                    | P & HA                               | 83.0                                  | 48.0                                       | No cracks                            |
| 3    | René 41     | 0.010                     | Parallel  | 85,766                    | 131,600                      | 29.5                    | W                                    | 97.5                                  | 34.2                                       | No cracks                            |
| 4    | René 41     | 0.010                     | Transverse                                      | 69,000                    | 129,500                      | 27.5                    | W                                    | 96.5                                  | 33.2                                       | No cracks                            |
| 5    | Hastelloy X | 0.005                     | Parallel  | 62,270                    | 97,030                       | 8.2                     | HA                                   | 80.2                                  | 70.4                                       | No cracks                            |
| 6    | Hastelloy X | 0.005                     | Transverse                                      | 63,870                    | 108,530                      | 24.0                    | HA, P, W                             | 90.8                                  | 10.4                                       | No cracks                            |
| 7    | Hastelloy X | 0.010                     | Parallel  | 53,170                    | 120,430                      | 33.8                    | P                                    | 100.0                                 | 14.4                                       | Slight cracking                      |
| 8    | Hastelloy X | 0.010                     | Transverse                                      | 53,270                    | 105,300                      | 21.5                    | P                                    | 93.3                                  | 41.4                                       | No cracks                            |

| Welding schedule |               |                 |               |            |         |
|------------------|---------------|-----------------|---------------|------------|---------|
| Test             | Speed,<br>ipm | Current,<br>amp | Arc,<br>volts | Argon, cfh |         |
|                  |               |                 |               | Shielding  | Backing |
| 1                | 6             | 4               | 2             | 8          | 8       |
| 2                | 6             | 4               | 2             | 8          | 8       |
| 3                | 6             | 9               | 2             | 12         | 12      |
| 4                | 6             | 9               | 2             | 12         | 12      |
| 5                | 6             | 4               | 2             | 8          | 8       |
| 6                | 6             | 4               | 2             | 8          | 8       |
| 7                | 6             | 9               | 2             | 12         | 12      |
| 8                | 6             | 9               | 2             | 12         | 12      |

<sup>a</sup> Coupons ground flush at welds.

<sup>b</sup> Welds 90 deg to testing direction.

<sup>c</sup> HA—heat-affected zone; P—base metal; W—weld.

<sup>d</sup> Percent weld efficiency = [ultimate psi (weld coupon) × 100] / [ultimate psi (base metal coupon)].

<sup>e</sup> Percent loss of elongation = [Percent elong. base metal—percent elong weld coupon] × 100 / (percent elongation base metal).

<sup>f</sup> Face and root bends were made with axis of bend parallel to weld direction; radiographs of all samples were acceptable.

apt that the René 41 weldments had small irregular areas which were dull and slightly rough. This condition is typical of René 41 weldments and does not appear to be detrimental.

There was very little difference between yield strength, ultimate strength, and elongation with respect to the rolling direction. The René 41 material displayed good weldability with good physical results. The elongation ranged from 16 to 25% with 85 to 97% weld efficiency. The Hastelloy X material, except for Test 5, displayed good weldability with elongation ranging from 21.5 to 33.8% with 90.8 to 100% weld efficiency. These test results were more consistent than those of the René 41. Test 5, however, showed much lower strength and percent elongation results. The coupons of test 5 fractured in the heat-affected zone. The low results were due, primarily, to a notch at the root of the weld created by the radius of the flange. This condition can be corrected by greater heat input to extend the fusion zone or shorter flange height, and a smaller flange radius. The notch condition is located at the arrow in Fig. 2.

Since all the elongation measurements were made on 2 in. gage lengths, the elongation values represent an overall condition including weldment, heat-affected zone and base metal.

## Test Results Obtained with Tungsten-Arc Process on 0.040 in. Material

Tests were made to determine the weldability of the medium gage materials of the same alloys, with and without filler metal and to determine the effects of the rolling direction.

The mechanical test results are tabulated in Table 4. The tests made parallel to the direction of rolling are slightly higher in strength and elongation values than those made transverse to the rolling direction. The differences are not great enough, however, to be of concern in design and application. The test results of specimens welded with and without filler metal are nearly equal. Therefore, filler metal is beneficial only to prevent thinning due to weld shrinkage and undercutting which occur on heavier sections due to higher heat input.

Mechanical test data indicate weld efficiencies ranging from 89.5 to 93.9% and elongation ranging from 19.3 to 26.2% for the René 41. The Hastelloy X ranges from 99.4 to 100% weld efficiency and from 23.3 to 38.8% elongation. Welds made with Hastelloy W filler metal cracked heavily when bent over a 2T radius. Slight cracking occurred during bending the other welds with a 2T radius indicating that a 2T bend for welded 0.040 in. thick material was too drastic. The Has-

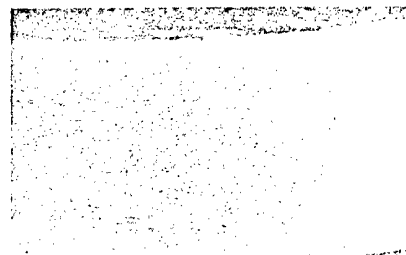


Fig. 3—0.040 in. René 41 square butt weld. No filler metal (test 11)



Fig. 4—0.040 in. Hastelloy X square butt weld. No filler metal (test 14)

telloy X welds were cleaner and smoother than the welds of René 41. Microstructures of the René 41 and Hastelloy X, without filler metal addition, are shown in Figs. 3 and 4 respectively. Figures 5 and 6 show the Hastelloy X square butt welds made with Hastelloy X and Hastelloy W filler metal respectively. Some segregation appears in the weld made with the Hastelloy W filler metal at the arrow of Fig. 6.

Table 4—Mechanical Properties and Weld Schedules of Solution Heat Treated and Butt Welded 0.040 in. Material<sup>a</sup>

| Test | 0.040 material | Filler metal diameter, in. | Testing to rolling direction | Yield strength, psi | Ultimate strength, psi | Elong. in 2 in., % | Location of fracture | Weld efficiency, % | Loss of elongation, % | 180 deg bend over 2T   |
|------|----------------|----------------------------|------------------------------|---------------------|------------------------|--------------------|----------------------|--------------------|-----------------------|------------------------|
| 9    | René 41        | 0.040 <sup>b</sup>         | Parallel                     | 77,230              | 132,890                | 26.2               | W                    | 93.9               | 39.5                  | Slight cracking        |
| 10   | René 41        | 0.040 <sup>b</sup>         | Transverse                   | 74,030              | 125,750                | 19.3               | W                    | 89.5               | 48.3                  | Slight cracking        |
| 11   | René 41        | none                       | Parallel                     | 77,070              | 132,490                | 23.2               | W                    | 93.7               | 45.3                  | Slight cracking        |
| 12   | Hastelloy X    | 0.040 <sup>b</sup>         | Parallel                     | 59,920              | 115,010                | 38.8               | P                    | 100.0              | 7.0                   | Slight cracking        |
| 13   | Hastelloy X    | 0.040 <sup>b</sup>         | Transverse                   | 59,790              | 109,860                | 23.2               | W                    | 96.6               | 40.8                  | Slight cracking        |
| 14   | Hastelloy X    | none                       | Parallel                     | 60,550              | 112,410                | 28.8               | W                    | 99.4               | 30.9                  | Slight cracking (face) |
| 15   | Hastelloy X    | 0.040 <sup>b</sup>         | Parallel                     | 63,320              | 113,580                | 34.7               | P, W                 | 100.0              | 16.8                  | Heavy cracking face    |
| 16   | Hastelloy X    | 0.040 <sup>b</sup>         | Transverse                   | 59,020              | 114,310                | 33.3               | P, W                 | 100.0              | 15.1                  | Heavy cracking root    |

| Welding schedule |           |              |            |                 |         |                 |
|------------------|-----------|--------------|------------|-----------------|---------|-----------------|
| Test             | Speed ipm | Current, amp | Arc, volts | Argon cfm       |         | Wire speed, ipm |
|                  |           |              |            | Shielding       | Backing |                 |
| 9                | 8         | 45           | 8          | 17              | 8       | 7               |
| 10               | 10        | 45           | 8          | 16 <sup>b</sup> | 20      | 10              |
| 11               | 13        | 45           | 8          | 18              | 12      | ...             |
| 12               | 10        | 45           | 8          | 16              | 15      | 14              |
| 13               | 10        | 45           | 12         | 16 <sup>b</sup> | 15      | 14              |
| 14               | 12        | 30           | 8          | 15 <sup>b</sup> | 5       | ...             |
| 15               | 15        | 55           | 8          | 18              | 8       | 16              |
| 16               | 15        | 55           | 8          | 18              | 8       | 17 1/2          |

<sup>a</sup> Filler metal of same material welded except Tests 15 and 16 which were Hastelloy W wire.

<sup>b</sup> 10 cfm helium gas.

Notes of Table 3 also apply to this table.

Hastelloy W contains higher percentages of nickel and molybdenum and lower percentages of chromium and iron than Hastelloy X.

### Test Results Obtained on Welded and Aged Material

When comparing the tensile properties of the aged coupons of Table 2

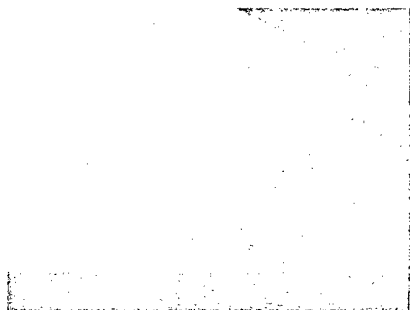


Fig. 5—0.040 in. Hastelloy X square butt weld with Hastelloy X filler metal (test 13)

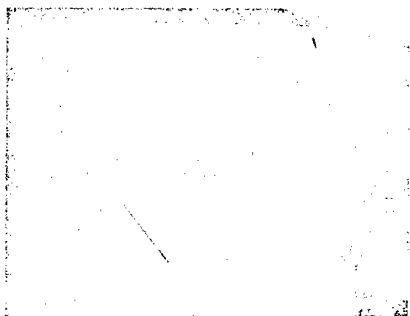


Fig. 6—0.040 in. Hastelloy X square butt weld with Hastelloy W filler metal (test 16)

to the base metal properties, it is noted that the René 41 aged coupon changed in relation to the solution treated base metal values approximately as follows: yield strength increase—75%; ultimate strength increase—25%; elongation decrease—71%. The change resulting from aging the Hastelloy X is erratic with respect to the yield and ultimate strength. However, an 80% decrease in elongation occurred.

The mechanical properties of the welded and aged coupons are tabulated in Table 5. The René 41 weld coupons aged after welding had weld efficiencies ranging from 96.3 to 100% and elongation ranging from 5.3 to 9.2%. Test 11.2 which was welded in the aged condition had a weld efficiency of 76.4% and an elongation of 3.7%. The low elongation was due primarily to the fact that the elongation was restricted to the weld and heat-affected zone which encompasses under 1/2 in. while the measurement was gaged over the 2 in. length. The low weld efficiency was due in part to the unaged condition of the weldment.

These test results indicate that aging of welded René 41 structures can be accomplished with good benefits and, if necessary, the welding of aged material is possible when the application allows for the resulting lower elongation. Aging Hastelloy X, welded or not, is nonbeneficial to the strength and detrimental to the elongation. Microstructures of

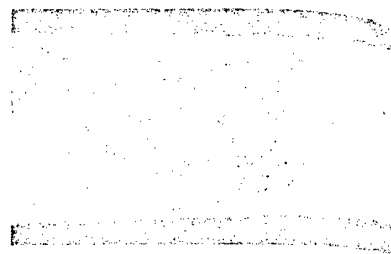


Fig. 7—0.040 in. René 41 square butt weld aged after welding (test 11.1)



Fig. 8—0.005 and 0.010 in. Hastelloy X flanged butt welds aged after welding (tests 5.1 and 7.1)

the aged welds are shown in Fig. 7 and 8.

### Welds and Circular Restraint Tests

Three-piece tee joints were welded to simulate the attachment of two edge members to a web center section. The welds were made with the center sections projecting on or two thicknesses above the two edge members, as recorded in Table 6, to provide for a burn-down joint. This furnishes the welds with light reinforcements on the face side and a fillet on each side of the centerpiece on the root side. Figure 9 shows the face and root side of tee weld

Table 5—Mechanical Properties of Solution Heat Treated Welded and Aged Coupons<sup>a</sup>

| Test              | Thickness, in. and material | Filler metal                | Yield strength, psi | Ultimate strength, psi | Elong in 2 in., % | Location of fracture | Weld efficiency, % | Loss in elongation, % | Bend test data   |
|-------------------|-----------------------------|-----------------------------|---------------------|------------------------|-------------------|----------------------|--------------------|-----------------------|--|
| 1.1               | 0.005 René 41               | 0.016 in. flange            | 136,370             | 170,030                | 8.6               | P & HA               | 98.5               | 45                    | 180 deg—8T OK<br>180 deg—2T broke                      |
| 3.1               | 0.010 René 41               | 0.016 in. flange            | 133,230             | 164,500                | 5.3               | HA                   | 100.0              | 28.4                  | 180 deg—2T broke                                       |
| 9.1               | 0.040 René 41               | 0.040 in. wire              | 137,600             | 182,200                | 9.0               | HA                   | 97.7               | 16.4                  | 90 deg—3T cracks                                       |
| 11.1              | 0.040 René 41               | None                        | 143,630             | 178,500                | 7.8               | W                    | 96.3               | 29.1                  | 4T bend cracked between 45 deg and 180 deg on face     |
| 11.2 <sup>a</sup> | 0.040 René 41               | 0.040 in. wire              | 106,090             | 141,630                | 3.7               | W                    | 76.4               | 66.4                  | 180 deg—2T slight crack on face                        |
| 5.1               | 0.005 Hastelloy X           | 0.016 in. flange            | 60,000              | 99,600                 | 6.0               | HA                   | 100.0              | 0                     | 180 deg—8T OK<br>180 deg—4T cracks                     |
| 7.1               | 0.010 Hastelloy X           | 0.016 in. flange            | 52,670              | 95,030                 | 8.0               | P                    | 95.0               | 36.0                  | 180 deg—2T cracks                                      |
| 12.1              | 0.040 Hastelloy X           | 0.040 in. wire              | 56,550              | 115,112                | 25.8              | P                    | 98.9               | 11.0                  | 90 deg—3T face OK<br>not cracked                       |
| 15.1 <sup>b</sup> | 0.040 Hastelloy X           | 0.040 in. wire <sup>c</sup> | 58,460              | 117,090                | 25.8              | P                    | 98.9               | 11.0                  | 3T root cracked at 60 deg<br>2T face cracked at 90 deg |
| 16.1 <sup>a</sup> | 0.040 Hastelloy X           | 0.040 in. wire              | 59,500              | 111,510                | 18.0              | W                    | 42.2               | 37.9                  | 180 deg—2T extensive cracks                            |

<sup>a</sup> The notes of Table 3 also apply to Table 5.

<sup>b</sup> Aged before welding.

<sup>c</sup> Hastelloy W filler metal.

Table 6—Tee Joint Welds and Circular Restraint Tests

| Test | Material    | Gage  | Weld          | Center piece projection | Radiograph grading      | Weld schedule <sup>b</sup> |       |                |                |     |
|------|-------------|-------|---------------|-------------------------|-------------------------|----------------------------|-------|----------------|----------------|-----|
|      |             |       |               |                         |                         | Amp                        | Volts | Shielding, ipm | Back- ing, cfh | cfh |
| 17   | René 41     | 0.005 | Tee           | 2T                      | Local porous areas      | 10                         | 8     | 5              | 12             | ... |
| 18   | René 41     | 0.010 | Tee           | 2T                      | Acceptable              | 13                         | 8     | 3              | 7              | ... |
| 19   | Hastelloy X | 0.005 | Tee           | 2T                      | Local porous areas      | 10                         | 8     | 5              | 12             | ... |
| 20   | Hastelloy X | 0.010 | Tee           | 2T                      | Local porous areas      | 25                         | 8     | 8              | 16             | ... |
| 21   | René 41     | 0.040 | Tee           | 1T                      | Acceptable              | 60                         | 9     | 8              | 18             | 8   |
| 22   | René 41     | 0.040 | Tee           | 1T                      | Acceptable <sup>a</sup> | 60                         | 8     | 8              | 12             | 5   |
| 23   | René 41     | 0.040 | Circular butt | ..                      | Acceptable <sup>a</sup> | Manual welds               |       |                |                |     |
| 24   | Hastelloy X | 0.040 | Circular butt | ..                      | Acceptable              | Manual welds               |       |                |                |     |

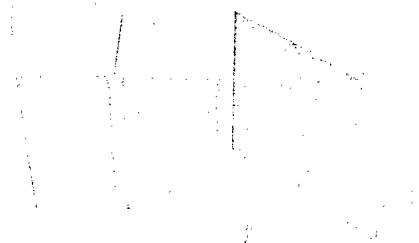
<sup>a</sup> Before and after aging.<sup>b</sup> Argon gas.

Fig. 9—0.040 in. Hastelloy X, 3 piece tee weld, face and root views (test 22)

made from 0.040 in. thick René 41 material. The welds have defects of irregular root penetration and lack of fusion at the root of the weld as shown respectively in Figs. 10 and 11.

The 0.005 and 0.010 in. thick plates were welded on a set of chill bars that had a square shoulder at

the root of the weld. No backing gas was used. Champering this edge would allow the fillet to drop through further thus increasing penetration and eliminating the lack of fusion at the bottom of the fillet. Porosity which developed during welding, as shown in Table 6, could be eliminated by adding backing gas.

The lack of fusion of the 0.040 in. thick material could be corrected by adjustment of the heat input.

The welding was done in a fixture having copper chill bars on the bottom and copper hold down bars at the top. The welds were made with a semiautomatic gas tungsten-arc electrode holder driven on an extended track of a stake welding unit.

Circular restraint tests were made

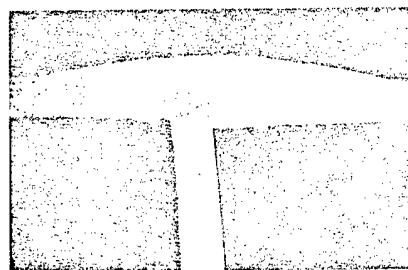


Fig. 10—0.010 in. René 41, 3 piece tee weld with irregular root penetration (test 18)

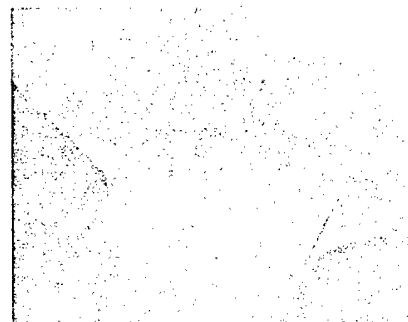


Fig. 11—0.040 in. Hastelloy X, 3 piece tee weld with lack of fusion at the fillets (test 22)

on the 0.040 in. materials to determine their susceptibility to cracking under the influence of weld stresses. The weld stresses were introduced by making a circular weld configuration as shown in Fig. 12.

An 8 x 8 in. section of butt welded sheet material was circular punched to obtain a circular blank about 3 in. in diam. The 8 x 8 in. section was then framed with a 1 in. wide section of 0.125 in. stainless steel spot welded in place to make the section more rigid. The circular blank was then rewelded in its

Table 7—Resistance Spot Weld Tensile Shear, Nugget Size and Weld Schedules

| No. of test coupons                      | Shear strength in lb |      |       | Avg nugget diameter, in. | Avg penetration, % | Weld Schedule      |                                       |         |      |       | Phase A | Electrode RWMA Class 2 |
|--|----------------------|------|-------|--------------------------|--------------------|--------------------|---------------------------------------|---------|------|-------|---------|------------------------|
|  | Avg                  | Min  | Range |                          |                    | Pre-heat           | Weld and Temper                       | Squeeze | Hold | Force |         |                        |
| 15                                       | 58                   | 40   | 30    | 0.044                    | 60                 | 10 <sup>(1)</sup>  | 10 <sup>(11)</sup> 10 <sup>(11)</sup> | 20      | 20   | 93    | ..      | 5/8 in. diam           |
| (0.005 René 41 to 0.005 René 41)         |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| 15                                       | 44                   | 30   | 20    | 0.034                    | 1                  | ...                | 15 <sup>(11)</sup> ...                | 27      | 7    | 151   | off     | 4 in. face radius      |
| (0.005 René 41 to 0.010 René 41)         |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| 15                                       | 44                   | 40   | 10    | 0.047                    | 36                 | ...                | 10 <sup>(11)</sup> ...                | 27      | ..   | 134   | off     | 4 in. face radius      |
| (0.005 Hastelloy X to 0.005 Hastelloy X) |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| 15                                       | 41                   | 35   | 10    | 0.052                    | 38                 | ...                | 10 <sup>(11)</sup> ...                | 27      | 7    | 134   | onf     | 1/2 in. diam           |
| (0.05 Hastelloy X to 0.010 Hastelloy X)  |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| 15                                       | 2196                 | 2035 | 275   | 0.190                    | 40                 | 38 <sup>(25)</sup> | 51 <sup>(31)</sup> 45 <sup>(41)</sup> | 4       | ..   | 2000  |         | 5/8 in. diam           |
| (0.040 René 41 to 0.040 René 41)         |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| 16                                       | 2095                 | 2000 | 200   | 0.22                     | 48                 | 38 <sup>(25)</sup> | 41 <sup>(31)</sup> 52 <sup>(41)</sup> | 4       | 2    | 2000  |         | 5/8 in. diam           |
| (0.040 Hastelloy X to 0.040 Hastelloy X) |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| Note                                     |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| Interface                                |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| Pulse                                    |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| Interval                                 |                      |      |       |                          |                    |                    |                                       |         |      |       |         |                        |
| 1  | 1                    | 1    | 1     | 1                        | 1                  | 1                  | 1                                     | 1       | 1    | 1     | 1       | 1                      |
| 2  | 1                    | 1    | 1     | 1                        | 1                  | 1                  | 1                                     | 1       | 1    | 1     | 1       | 1                      |
| 3  | 3                    | 3    | 3     | 3                        | 3                  | 3                  | 3                                     | 3       | 3    | 3     | 3       | 3                      |
| 4  | 2                    | 2    | 2     | 2                        | 2                  | 2                  | 2                                     | 2       | 2    | 2     | 2       | 2                      |
| 5  | 5                    | 5    | 5     | 5                        | 5                  | 5                  | 5                                     | 5       | 5    | 5     | 5       | 5                      |
| 6  | 2                    | 2    | 2     | 2                        | 2                  | 2                  | 2                                     | 2       | 2    | 2     | 2       | 2                      |

Preheat, weld and temper are in %; phase shift squeeze and hold are in cycles.

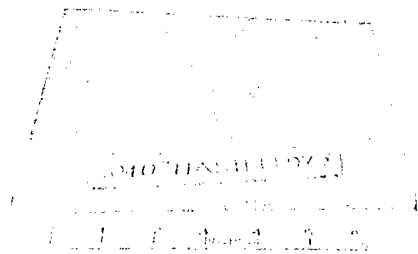


Fig. 12—0.040 in. Hastelloy X, circular restraint weld (test 24)

original position forming a circular weld insert.

Radiographs made of the welded parts showed no apparent cracking. The parts were then aged and re-radiographed. No apparent cracks were found after aging, although the plates had warped considerably. The erratic warping may be attributed at least in part to the stainless steel framework which has thermal expansion properties lower than the nickel-base alloys. These tests indicate a low susceptibility of René 41 and Hastelloy X material to cracking from restrained stresses.

### Spot Welding Test Results

Spot welding test results and the weld schedules used to obtain the results are summarized in Table 7. Tests 25-28 were made to determine the weldability of the foil material. Evaluation of the mechanical test data and the photomicrograph of tests 25 and 28 of Fig. 13 indicate the weldability of the two alloys is good. It is necessary to have low heat input, long heat time and high pressure to produce the weld with the required nugget diameter without expulsion.

The good weldability has been proved only with resistance welding equipment of a precision type, 3-phase, with separate phase shift and

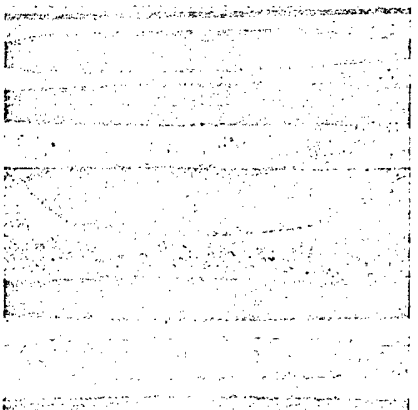


Fig. 13—0.005 in. René 41 acceptable spot weld (test 25); 0.005 in. to 0.010 in. René 41 unacceptable spot weld (test 26); 0.005 in. to 0.010 in. Hastelloy X acceptable spot welds (test 28)

timing controls for preheat, weld and post weld functions.

Test 26 of Fig. 13 shows a lack of penetration in the thinner sheet and is not considered an acceptable weld. The fault can be corrected by decreasing the face radius of the electrode contacting the thinner sheet, and increasing the face radius of the electrode contacting the thicker sheet.

Good spot welds can be obtained in the 0.040 in. gage material without difficulty. In order to obtain the desired weld nugget diameters and to prevent expulsion, it is necessary to use high pressure and relatively long heat times. Figure 14 shows a case of slight expulsion of a segregate material at the faying surface, and an area of coring or incipient melting adjacent to the faying surface projected from the boundary of the nugget. Figure 15 shows a complex pattern of segregation. These conditions were found in both alloys but they had little if any effect on the strength of the welds. Other investigators have identified the segregate as a eutectic. Their work indicates that their presence resulted in lower property values.

### Cleaning Procedures

It was not the intent of this project to develop cleaning procedures for production purposes. The methods tried were on a laboratory scale only for the purpose of adequate cleaning to produce consistent welding results.

As-received material was sheared to size, vapor degreased and pickled in the following pickling solution which removes light oxide, leaving a uniform matte surface:

| Composition   | Volume % |
|---|----------|
| Proprietary fluoride solution   | 14       |
| (42% Be) nitric acid  | 34       |
| Water   | 52       |
| Treatment: 10 min immersion in solution at room temperature, water rinse and dry. |          |

An attempt was made to evaluate the effects of cleaning Hastelloy X material by comparing the tensile shear results of 10 spot welded coupons, cleaned with Chemicals A and B, scale conditioners followed by pickling as previously mentioned. To eliminate as many variables as possible, each chemically cleaned coupon was spot welded, using the same welding schedule, to a coupon which had been manually abrasive cleaned.

Referring to Table 8, it is interesting to note that the coupon in the

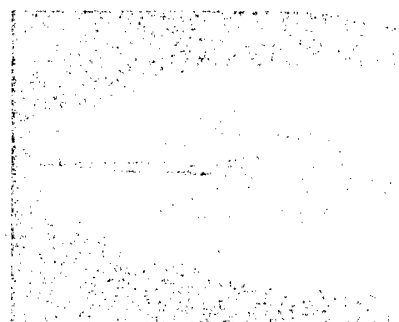


Fig. 14—0.040 in. Hastelloy X, spot weld containing segregate expulsion at coring or incipient melting (test 30)

as-received uncleaned condition (No. 6) had a tensile shear strength of 1375 lb. The average tensile shear of the coupons cleaned by varying time and temperature in chemical solutions was 1680 lb, and the average tensile shear of 20 coupons cleaned with emery cloth was 2065 lb. These results illustrate that a wide variation in shear strength occurs when a variation of cleaning methods are used. If reproducible results are desired, all material must be cleaned similarly.

### Conclusions

Fusion welded René 41 and Hastelloy X materials in foil gages of 0.005 and 0.010 in. display good welding characteristics. Cleaning, edge preparation, precision fixtures and precision welding equipment are essential to produce sound welds. It is necessary to use inert gas backing to prevent excessive scaling and oxide formation, caused by elements in the atmosphere, when the material is at molten temperatures.

Both materials have satisfactory elongation properties and good ultimate and yield strength when welded in the solution heat treated condition. René 41 may be aged after welding if increased strength is desired at the sacrifice of elongation. It may also be joined in the unrestrained condition after aging, resulting in a ductile weld having an ultimate strength of 140,000 psi.

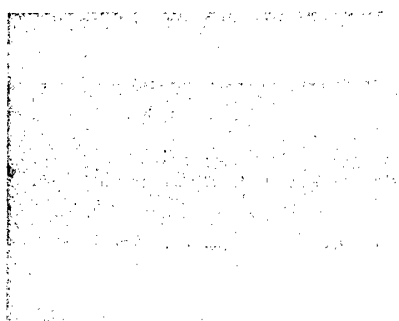


Fig. 15—0.040 in. Hastelloy X, spot weld containing complex segregation (test 30)

Table 8—Cleaning 0.040 in. Hastelloy X with Chemicals Prior to Spot Welding

| Coupon no.               | Prior condition                  | Cleaning Compound                   |                                     |                         |           | Tensile, <sup>b</sup> shear/lb |
|--------------------------|----------------------------------|-------------------------------------|-------------------------------------|-------------------------|-----------|--------------------------------|
|                          |                                  | Chemical A<br>@ 265-275<br>° F, min | Chemical B<br>@ 200-210<br>° F, min | Chemical C<br>Time, min | Temp, ° F |                                |
| 1                        | As received                      | 30                                  | 30                                  | 25                      | 120       | 1450                           |
| 2                        | As received                      | ...                                 | 30                                  | 20                      | 120       | 1450                           |
| 3                        | As received                      | ...                                 | 45                                  | 23                      | 135       | 1600                           |
| 4                        | As received                      | 30                                  | 45                                  | 23                      | 135       | 1850                           |
| 5                        | As received                      | 60                                  | 60                                  | 25                      | 120       | 1675                           |
| 6                        | As received                      | ...                                 | ...                                 | ...                     | ...       | 1375                           |
| 10                       | Vapor degrease and alkaline wash | ...                                 | ...                                 | 16                      | 90        | 1500                           |
| 11                       | Vapor degrease and alkaline wash | ...                                 | 45                                  | 25                      | 120       | 1800                           |
| 12                       | Vapor degrease and alkaline wash | 45                                  | 45                                  | 25                      | 135       | 1775                           |
| 13                       | Vapor degrease and alkaline wash | ...                                 | ...                                 | 25                      | 120       | 1925                           |
| Cleaned coupons avg 1680 |                                  |                                     |                                     |                         |           |                                |
| Control coupons avg 2095 |                                  |                                     |                                     |                         |           |                                |

<sup>a</sup> HF-HNO<sub>3</sub> solution formulations.  
<sup>b</sup> Spot welds made 72 hr after cleaning.  
 Control—emery cleaned—20 coupons.

and an estimated weld elongation of 20 to 30%. The effects of an

aging heat treatment on Hastelloy X was to decrease the elongation

without improving the strength potential.

The 0.040 in. gage materials display similar physical characteristics as the foil gages. With the exception of inert gas backing being required, production welding facilities and fixtures used for austenitic stainless steel are suitable for welding these two materials.

To comply with aircraft and missile radiographic standards, it is necessary to have clean material for welding. The material must be free of grease and scale. Pickling is the best method for removing heavy scale; however, sand or vapor blast may be used, followed by a light pickle to remove surface particles. Oil should be removed prior to welding by hot vapor degreasing. Shear edges should be draw-filed or machined to remove embedded particles that cause porosity.

Resistance welding requires the same surface cleanliness and fit-up as used for austenitic stainless steel. The welding equipment, however, must be three-phase and capable of higher pressures, greater accuracy and flexibility of control greater than the minimum requirement for stainless steel.

## University Welding Research Directory

The Welding Research Council (WRC) was established by interested Engineering Societies and Trade Associations to accomplish certain objectives. These objectives simply stated are: (1) to conduct coordinated cooperative research in welding and closely allied fields; (2) to eliminate research information; (3) to promote welding research in universities and (4) to provide means for cooperation, interchange of ideas and information with similar agencies abroad. One of the several committees of WRC is the University Research Committee.

One of the principal objectives of the University Research Committee is to stimulate and encourage research in welding and closely allied fields in the various universities

of the United States. The Council has found from past experience that the research dollar goes farther in the University research laboratories than in other laboratories. Furthermore, the by-product of the training and education of young men and professors in the various sciences related to welding engineering might be more important in the long run than the solution of specific problems. In recent years, Industry has been particularly appreciative of these specially trained young engineers and scientists.

To assist Industry and Government Agencies in making contacts directly with Universities and in placing specific research problems in the Universities for solution, the Welding Research Council compiles and publishes a University Welding Research Directory every two or three years. The Third Edition of the Directory was published in February 1962. The Directory describes the facilities and staff

available at each of the Universities participating in Welding Research Council projects. It describes each department engaged in welding research, giving in detail the University's research facilities and operations, a list of the research officers of the University and staff members, and a classification of typical research projects previously carried out or now under way. One section of the Directory presents a list of welding research problems that University Professors would prefer to work on if funds were available. Each company desiring to sponsor research is urged to make direct contacts with the Universities. The Welding Research Council, however, will be glad to assist at all times as far as possible.

The Directory has been sent to subscribers of the Welding Research Council and is available to others at a cost of \$2.00 from the Welding Research Council, 345 East 47th Street, New York 17, N. Y.